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Research paper

Gravitation near the Schwarzschild radius

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Abstract

The problem of gravitation near the Schwarzschild radius is addressed. The pressure due to free fall velocity is introduced. At the Schwarzschild radius, this pressure produces the force balancing the gravity thus stopping the collapse of the matter. The minimum radius of the source of gravity is defined as a radius at which the proton reaches the Planck energy. The compact object as a thin shell at the minimum radius is considered. The proton is assumed to decay at the Planck scale into positron and hypothetical Planck neutrinos. Under accretion onto the compact object, half the protons decay, and the other protons retain at the minimum radius.

Keywords: *Compact Object; Free Fall Pressure; Gravitation; Proton Decay; Schwarzschild Radius.*

1. Introduction

According to general relativity (Misner et al. 1973), a body contracted to the Schwarzschild radius, $r_g = 2GM / c^2$, forms a black hole bounded by the so called event horizon. A body with a mass above ~3 solar mass will collapse into a black hole. As an alternative to black hole, the model of the gravastar was proposed (Mazur & Mottola 2004, Chapline 2003). The model contains a vacuum in the interior and, instead of event horizon, a thin layer of stiff matter. The core of the gravastar with a negative pressure produces the repulsive force which stops the collapsing matter at the radius close to the Schwarzschild radius. To this end, several solutions to avoid the development of black hole event horizon within the classical theories have been discussed, e.g. (Corda & Mosquera Cuesta 2011) and references therein.
The surface of the gravastar is a suitable site for the hypothetical decay of proton (Chapline 2003). When interpreting Sgr A^* as a gravastar, the decay of the protons at Sgr A^* may explain (Barbieri & Chapline 2012) an excess of 511 keV radiation from the centre of the Galaxy (Prantzos et al. 2011). The observed flux of 511 keV radiation is consistent with the accretion rate onto Sgr A^* (Khokhlov 2014). The observed luminosity of Sgr A^* imposes constraints onto the mode of the decay of proton (Khokhlov 2014), ruling out the mode of the grand unification, $p \to e^+ \pi^0$ (Georgi & Glashow 1974), and admitting the mode of the decay of proton at the Planck scale into positron and hypothetical Planck neutrinos, $p \to e^+ 4\nu_{Pl}$ (Khokhlov 2011). Planck neutrinos are assumed to take part only in the gravitational interaction that may explain the discrepancy between the accretion rate and the luminosity of Sgr A^*.
The model of the gravastar was considered in Khokhlov (2017). In the model, half the accreting protons decay at the Planck scale, and the other accreting protons retain at the gravastar. The protons retaining at the gravastar are in the chaotic motion in the transverse direction. The centrifugal force of the protons balances the gravity of the protons. In this case, there is no need in the vacuum with a negative pressure inside the gravastar to oppose the gravity of the gravastar.
In the present paper, we shall consider the model of the compact object near the Schwarzschild radius. Along with the gravity of the matter, we shall take into account the pressure due to the free fall motion of the matter. Also, we shall consider the role of the decay of the protons in the formation of the compact object.

2. Model of the compact object near the Schwarzschild radius

Consider the gravitation generated by the matter of the mass m. We shall consider the problem in the local frame of the centre of mass of the matter wherein the Newtonian gravity holds. The gravitational potential at the radius r from the centre of mass of the matter is given by

$$\Phi = -\frac{Gm}{r} \tag{1}$$

Where G is the Newton constant. The force due to gravity at the radius r is defined in the local frame as

$$f_g = -\frac{d(m\Phi)}{dr} = -\frac{Gm^2}{r^2}. \tag{2}$$

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The gravity at the radius r produces a free fall velocity of the probe particle

$$v = \left(\frac{2Gm}{r}\right)^{1/2}. \tag{3}$$

The matter within the radius r creates the pressure, hereafter we shall call it free fall pressure. The force due to free fall pressure is defined in the local frame as

$$f_p = \frac{m}{2}\frac{dv^2}{dr} = \frac{Gm^2}{r^2}. \tag{4}$$

The force due to free fall pressure is of the same value as the force due to gravity and of the opposite direction.
The gravitation propagates with the speed of light c. The free fall pressure extends with a free fall velocity. The gravitational potential is established with a time delay

$$t_g = \frac{r}{c}. \tag{5}$$

The free fall pressure is established with a time delay

$$t_p \sim \frac{r}{v}. \tag{6}$$

At the radii much more than the Schwarzschild radius, averaging the free fall velocity gives a factor of 2/3 to the time delay eq. (6). When the free fall velocity is significantly less than the velocity of light, the pressure time delay eq. (6) is significantly more than the gravitational time delay eq. (5), and the free fall pressure can be neglected. When approaching the Schwarzschild radius, the free fall velocity tends to the velocity of light, the pressure time delay gets comparable to the gravitational time delay, and the free fall pressure becomes noticeable. At the Schwarzschild radius, the gravitational potential and the free fall pressure are established with the same time delay, and the free fall pressure balances the gravity. Therefore, the free fall pressure stops the collapse of the matter at the Schwarzschild radius.
The total acceleration of the particle at the Schwarzschild radius, being the sum of the acceleration due to gravity and the acceleration due to free fall pressure, is equal zero. The particle falling from infinity with a free fall velocity will return at the Schwarzschild radius and move back to infinity. The collapsing matter, consisting of the particles with a free fall velocity, is not able to form the compact object at the Schwarzschild radius. The velocity of the particle, moving along the circular orbit at the Schwarzschild radius, is given by

$$v = \left(\frac{Gm}{r_g}\right)^{1/2} = \frac{c}{\sqrt{2}}. \tag{7}$$

This is less than the free fall velocity by a factor of 1/√2. One may expect that the colliding particles at the Schwarzschild radius would emit electromagnetic radiation thus reducing their kinetic energies and in turn their velocities. However, the particles are in the gravitational potential well which value is equal to the kinetic energy of the particles. Therefore, conversion of the kinetic energy of the particle in the electromagnetic radiation is impossible. The problem was studied in Khokhlov (2017).
The relativistic energy of the particle grows to infinity at the Schwarzschild radius. It is reasonable to think that the energy of the particle is limited at the Planck scale. In general relativity (Misner et al. 1973), the energy of the proton falling in the gravitational field generated by the matter of the mass m is given by

$$E'_p = \frac{m_p}{(1 - 2Gm/rc^2)^{1/2}} \tag{8}$$

Where m_p is the mass of proton. When approaching the Schwarzschild radius, the velocity of the proton tends to the velocity of light, and the energy of the proton tends to infinity. Assume that the Planck energy is the limiting energy of the proton. Putting the Planck energy into eq. (8) one can obtain the minimum radius of the source of gravity

$$r_{\min} = \frac{2Gm/c^2}{1 - m_p^2/m_{Pl}^2} \tag{9}$$

Where m_{Pl} is the Planck mass. The minimum radius of the source of gravity is close to the Schwarzschild radius, with the correction

$$1/(1 - m_p^2/m_{Pl}^2).$$

The formation of the compact object near the Schwarzschild radius was considered in the model of the gravastar (Khokhlov 2017). Given the free fall pressure, one can develop the model of the compact object without introducing the gravitational vacuum as it is in the model of the gravastar. We shall apply the results obtained in Khokhlov (2017) to the model of the compact object without the gravitational vacuum. The model is based on the assumption that the energy of the protons accreting onto the compact object is split into two modes

$$E' = (E'_+ E'_-)^{1/2}. \tag{10}$$

Suppose that the radius of the compact object is the minimum radius eq. (9). Half the protons have the energy

$$E'_{+} = \frac{m_p}{(1 - 2Gm / r_{\min} c^2)^{3/4}} \tag{11}$$

And the other half the protons have the energy

$$E'_{-} = \frac{m_p}{(1 - 2Gm / r_{\min} c^2)^{1/4}}. \tag{12}$$

The energy eq. (12) corresponds to the velocity

$$v = \left(\frac{Gm}{r_{\min}} \right)^{1/2} \approx \frac{c}{\sqrt{2}}. \tag{13}$$

The proton with the velocity eq. (13) will move along the circular orbit, retaining at the minimum radius. The protons with the velocity eq. (13) are supposed to be in the chaotic motion in the transverse direction. In this case, the centrifugal acceleration of the protons balances the gravity of the protons. It is assumed that the proton decays at the Planck scale into positron and hypothetical Planck neutrinos, $p \rightarrow e^+ 4\nu_{Pl}$ (Khokhlov 2011). In the gravitational field of the mass m, the energy of the proton eq. (11) is given by

$$E_{+} = \frac{m_p}{(1 - 2Gm / r_{\min} c^2)^{1/4}}. \tag{14}$$

The protons with the energy eq. (14) decay, and the arising particles go from the minimum radius to infinity.

So, we consider the compact object as a thin shell at the minimum radius near the Schwarzschild radius. The protons constituting the compact object are in the chaotic motion in the transverse direction, with the energy of the protons eq. (12). The protons of the compact object are in the gravitational potential well which value exceeds the energy of the protons. Therefore, emission of the electromagnetic radiation from the compact object is suppressed, and the compact object looks like a black object. The matter of the compact object can be thought of as a dark matter. The luminosity of the compact object can be explained by the liberated gravitational binding energy of the electrons falling onto the compact object as it was shown in the model of the gravastar (Khokhlov 2017).

In the original model of the gravastar (Mazur & Mottola 2004, Chapline 2003), the vacuum inside the Schwarzschild radius creates a negative pressure, preventing contraction of the matter. In the model under consideration, the free fall pressure of the matter stops contraction of the matter at the Schwarzschild radius. The decay of half the protons at the minimum radius leads to reducing the kinetic energy of the other half the protons. The reduced kinetic energy of the protons creates the centrifugal force, balancing the gravity of the protons. As a result, the compact object forms as a thin shell at the minimum radius. Such a compact object is similar to the gravastar but the physics behind the formation of the compact object is different from that for the gravastar.

Hypothetical Planck neutrinos, arising in the decay of protons are supposed to take part only in the gravitational interaction. Therefore, Planck neutrino may be thought of as a dark matter candidate (Khokhlov 2015). Planck neutrino is supposed to be a massless particle propagating with the velocity of light. It can be classified as a hot dark matter. The model of the galaxy with hot dark matter was presented in Khokhlov (2018,2020b). It may explain the rotation curves of the galaxies. The models with hot dark matter were rejected as they are not able to describe the galaxy formation (Trimble 1987). In these models, the hot dark matter is present in the universe from the early times. On the contrary, we assume that the galaxies formed from the baryonic matter, and the hot dark matter comes there later. To this end, Planck neutrino may be considered as a candidate for ultra high energy cosmic rays. Planck neutrinos may explain the cosmic ray spectrum above 5×10^{18} eV (Khokhlov 2020a).

3. Conclusion

We have addressed the problem of gravitation near the Schwarzschild radius. We have shown that the matter, along with the gravitation, creates the pressure, we call it free fall pressure. When the free fall velocity is small in comparison with the velocity of light, the free fall pressure can be neglected. At the Schwarzschild radius, the free fall velocity is equal to the velocity of light, and the force due to free fall pressure balances the gravity. Therefore, the collapse of the matter ends at the Schwarzschild radius.

We have assumed that the energy of the particle is limited at the Planck scale. The radius of the source of gravity at which the proton reaches the Planck energy is the minimum one close to the Schwarzschild radius. It is reasonable to consider the compact object as a thin shell at the minimum radius. To form the compact object near the Schwarzschild radius it is necessary to reduce the kinetic energy of the accreting protons. We have assumed that the proton decays at the Planck scale into positron and hypothetical Planck neutrinos. The decay of half the accreting protons leads to reducing the kinetic energy of the other protons thus making possible the formation of the compact object. Such a compact object can be considered in the model of the gravastar but the physics behind the formation of the compact object and the gravastar is different.

The matter of the compact object contracted to near the Schwarzschild radius is in the gravitational potential well that suppresses emission of the electromagnetic radiation from the compact object. Therefore, the matter of the compact object can be thought of as a dark matter. Hypothetical Planck neutrinos arising in the decay of the protons are supposed to take part only in the gravitational interaction. Therefore, Planck neutrinos can be thought of as a dark matter. Thus, we consider two kinds of dark matter as a compact object and as Planck neutrinos.

References

[1] Barbieri J & Chapline G (2012) Signature for the absence of an event horizon. Physics Letters B 709, 114–117. https://doi.org/10.1016/j.physletb.2012.02.003.

[2] Chapline G (2003) Quantum phase transitions and the failure of classical general relativity. International Journal of Modern Physics A, 18, 3587–3590. https://doi.org/10.1142/S0217751X03016380.
[3] Corda C & Mosquera Cuesta HJ (2011) Irreversible gravitational collapse: black stars or black holes? Hadronic Journal 34, 149–159.
[4] Georgi H & Glashow S (1974) Unity of all elementary-particle forces. Physical Review Letters 32, 438–441. https://doi.org/10.1103/PhysRevLett.32.438.
[5] Khokhlov DL (2011) Gravitational wave in the theory with the universal charge. Open Astronomy Journal 4, SI 1, 151–153. https://doi.org/10.2174/1874381101004010151.
[6] Khokhlov DL (2014) Constraints on the decay of the protons falling onto Sgr A*. Physics Letters B 729, 1–2. https://doi.org/10.1016/j.physletb.2013.12.055.
[7] Khokhlov DL (2015) Dark matter radiation from Sgr A*. Astrophysics and Space Science 360, 27. https://doi.org/10.1007/s10509-015-2541-y.
[8] Khokhlov DL (2017) Energy of the particle falling onto the surface of the gravastar. International Journal of Modern Physics and Application 4, 8–11.
[9] Khokhlov DL (2018) Model of the galaxy with hot dark matter. Open Astronomy 27, 294–302. https://doi.org/10.1515/astro-2018-0034.
[10] Khokhlov DL (2020a) Planck neutrinos as ultra-high energy cosmic rays. Open Astronomy 29, 40–46. https://doi.org/10.1515/astro-2020-0005.
[11] Khokhlov DL (2020b) The hot dark matter model: Further investigation. Odessa Astronomical Publications 33, 11–17. https://doi.org/10.18524/1810-4215.2020.33.216299.
[12] Mazur P & Mottola E (2004) Gravitational vacuum condensate stars. Proceedings of the National Academy of Sciences 101, 9545–9550. https://doi.org/10.1073/pnas.0402717101.
[13] Misner CW, Thorne KS, Wheeler JA (1973) Gravitation. Freeman, San Francisco.
[14] Prantzos N et al. (2011) The 511 keV emission from positron annihilation in the Galaxy. Reviews of Modern Physics 83, 1001–1056. https://doi.org/10.1103/RevModPhys.83.1001.
[15] Trimble V (1987) Existence and nature of dark matter in the universe. Annual Review of Astronomy and Astrophysics 25, 425–472. https://doi.org/10.1146/annurev.aa.25.090187.002233.